FLOODSTAND-deliverable:

D0.4b Progress in RTD during the second half of the project

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FLOODSTAND	**Integrated Flooding Control and Standard for Stability and Crises Management**	FP7-RTD- 218532

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Abstract: This deliverable lists the objectives of the project for both the first half of the project duration and describes how they were met in each work package. It also makes a more detailed view on the RTD work progress in each part of the project and describes additionally the achievements during the last 18 months of the project. Main results of the project within this project period (18 months) are by no doubt the utilization of the experimental test results as well as all the other analyses carried out to produce methods, data etc. to support flooding simulations and analysis.

Acknowledgements
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Contents

1. Executive summary

Project FLOODSTAND was established to derive most of the missing data for validation of time-domain numerical tools used in the assessment of ship survivability and to develop a standard for a comprehensive measure of damaged ship stability by concentrating on the risk of flooding. The second 18-month period showed the following efforts and achievements:

Two cruise ship designs, developed by STX Finland and Meyer Werft GmbH in WP1 to meet the current regulations, were utilized in WP1(T1.2) for testing the developed methods and standards. No dramatic results could be seen with the changes studied, but every step taken through research towards better understanding of the involved phenomena and the increase in the reliability of the data used formed together a clear improvement in comparison with the previous state of art. In addition to WP1 these cruise ship designs were also used in several Tasks of WP2, WP3 and WP7 during the second half of the project.

The first (18 month-) period of the project was emphasized in the research efforts of WP2. However, the second period was fruitful, too. Two WP2-deliverables were submitted. Guidelines based on the results of the door tests (experimental and numerical), guidelines on how to consider the effects of the non-watertight doors was the topic of the former, whereas the second report described the sensitivity analysis, and the results thereof, related to the values obtained earlier in Task 2.2 and Task 2.3. Articles related to both topics (doors and openings & cross ducts) were submitted to IMO SLF 53 and IMO SLF 54. Two scientific papers around the same topics were published, too.

In WP3, a new inverse method for definition of flooding and damage extents based on flood level sensor data was developed and documented. The accuracy of the method was verified and the results were found good. Improved method for prediction of progressive flooding was developed and reported. Computational performance has significantly improved from the initially used time-domain simulation without significant sacrifice of accuracy. This method forms a solid basis for decision making applications to be used on board ships. In the task: Impact of ship dynamics, a new approach on calculation of the motions of a damaged ship was developed. A combination of LAIDYN and NAPA software was carried out. The design of flood sensor systems, in Task 3.3, a guideline for design of flood sensor systems to be used for decision making systems was developed. The guideline discusses the type, required number and location principles of flood water sensors to achieve sufficient accuracy of the flooding prediction calculations (task 3.1).

In WP4, Stochastic ship response modeling, an analytical model for prediction of the time to capsize (ttc) after flooding was derived. A hybrid model of ship stability deterioration process was also developed. The uncertainty (concerning predominantly the extent of flooding) should be minimized and methods, perhaps such as derived in this project, reliable enough for wider use, are recommended to be used as support for systematic judgement on criticality of the situation rather than rely solely on subjective judgement of the crew without sufficient information.

Systematic series of experimental and numerical simulations for the ttc, of a damaged ROPAX ship[1] in waves, were also carried out. Based on the numerical simulations it was found that:

- Sea wave characteristics (wave height and peak period) are the most determining parameters for the TTC. A significant spread of TTC may occur, when the significant wave height is close to the critical wave height that corresponds to the damage case. Therefore capsize times later than 1 hour are rare events and may occur for wave heights very close to the critical wave height.
- The TTC appeared to be short, actually, no time available for an orderly evacuation of (non-surviving) ROPAX ships[1], when the damage events occur in presence of rough waves and the damage scenario involves the flooding of their large and wide car deck. If the ship does not capsize for the specific accident conditions, the evacuation itself becomes questionable and dependent on the confidence for the estimated probability to survive.

[1] complying with damage stability requirements of SOLAS'74, as the benchmark ROPAX used for the studies within WP4

• The present investigation and findings regarded Time to Capsize due to accumulation of water in large spaces above waterline due to wave actions. Other capsize modes were not considered. So, similar investigations for other modes of capsize should be conducted in order to complete the picture for TTC.
• The above conclusions, based on a large number of systematic numerical tests, maybe regarded with high confidence with respect to the observed characteristics of TTC. They are in general supported by results of similar case studies conducted for other sample, so that a generalization of the conclusions for the TTC of ROPAX[1] ships appears straightforward

The conclusions of WP4 can be condensed in the following statements:
• Loss of stability is a stochastic process
• Three distinctive modes governing safety are:
  – Abundant stability (50%-60%)
  – Residual stability (20%-30%)
  – NO stability (10%-20%)
• Method of fast assessment is proposed
• The major source of uncertainty is the information of extent of flooding

In “Rescue process modeling”, WP5, the significant results achieved in the four tasks (T5.2-T5.5), completed during the second 18-month period, were:
- A list of obstacles in rescue process has been defined
- All obstacle matrices have been calculated
- Several key parameters have been derived from WP5 results that have a significant influence on the expected number of casualties. These included:
  -- The Sea State is the main parameter influencing the fatality rate
  -- In severe sea states, the manoeuvrability performance of LSAs to clear off the vessel is predominant

In WP6 it was aimed to establish and integrated standard for decision making, reflecting in a balanced manner the societal concerns pertinent to a “large” loss. The proposed procedure reflects the considerable uncertainty not resolvable with today’s technology, human element and judgement in crises, as well as the knowledge on stochastic nature of ship stability deterioration process. The decision making process is complex, however the proposed criterion and steps are straightforward, auditable and mirror common sense reflection on reality of circumstances known to occur in crises. In addition an advanced procedure for maintaining preperdness at all times have been derived, and tested in real life environment.

WP7, was organized with the aim of testing the FLOODSTAND approaches in view of the mitigation of the casualty risk of passengers onboard ships associated with the ship flooding hazard. The two developed approaches of FLOODSTAND, to be tested, were those of the “FLOODSTAND for crisis management” and the “FLOODSTAND for flooding control” approach. The research resulted in three new deliverables (reports). The main results of this final part of the work can be condensed in the following items:

- The onboard detection of the damage extent, which determines the ability to assess the ship’s survivability, remains an open challenge for the onboard applications that deal with the survivability of the ship in flooding casualties.

- Additional evidences were generated indicating that the available time for orderly evacuation of both RoPax and cruise ships engaged in flooding incidents is much shorter than it is currently assumed. This may significantly affect the regulatory assumption for the safe evacuation of passenger ships.

2. Introduction

This report is written to describe the objectives, the work done and the results achieved during the second half of the project FLOODSTAND (218532), which was started in September 2010 and lasted till the end of February 2012. However, for practical reasons some reference to the first half, and the results achieved during it, is also made. Originally, this report, deliverable 0.4b was planned to simultaneously stand for the last (second 18 month) periodic report of the project. However, a change to the original plan (from the DoW) was made based on the recommendations from EC. Thus, the contents of this report has been changed from the original plan to concentrate more on the RTD issues in the project.

An other distinction between the periodic report and this deliverable is the audience. Unlike periodic report, this report is not written just for the Commission. It is a public report and the readers of this report may include, in addition to the EC and the project participant organisations, their empoyees and members of the project's Advisory Committee, readers from the whole society, including the scientific community, industry, civil society, policy makers, and medias, as well as any interested professional.

3. Project objectives

There are two main objectives (with further sub-objectives) for the whole duration of the project:

a) Increase the reliability of flooding simulation tools in design and onboard use by establishing modelling principles and uncertainty bounds, in particular by striving to the following subobjectives of the different Work Packages:

- Objectives of WP1: Establishing guidelines for modelling leaking through closed doors and the critical pressure head for collapsing under the pressure of floodwater.
- Objectives of WP2: Simplified modelling of pressure losses (discharge coefficients) in flows through typical openings. Feasible and realistic modelling of compartments with complex layout, such as cabin areas, for flooding simulation tools.
- Objectives of WP3: Use of flooding monitoring systems and time domain simulation for assessing the damage and flooding extent onboard the damaged ship.

b) Establish a method for instantaneous classification of the severity of ship flooding casualty, with the following subobjectives of the different Work Packages:

- Objective of WP4: Stochastic ship response modelling: establish requirements and uncertainty bounds for methods for prediction of the time it takes a ship to capsize or sink after damage.
- Objective of WP5: Rescue process modelling: establish requirements and uncertainty bounds for models of mustering, abandonment and rescue operations.
- Objective of WP6: Standard for decision making in crises: establish a loss function *loss*(*N*) and
- ( )*N i i p N decision* for the integrated standard. The loss function must reflect in a balanced manner the societal concerns pertinent to a “large” loss. The ( ) *N i i p N decision* will reflect the above requirements on the methods to be used for generating basis information on stability, evacuation and rescue process as well as the associated uncertainty.
- Objective of WP7 Demonstration: develop implementation system and test effectiveness of the standard in rating different decisions for various casualty cases as well as test the approach in design environment.

3.1 Project objectives for the second half of the project and how they were met

This sub-chapter provides an overview of the project objectives for the reporting period in question, as included in Annex I to the Grant Agreement (DoW). This is an extended version of the similar sub-chapter in D0.4a, with the additions concerning the results of second period.

3.1.1 Objectives of Work Package 1 (WP1): Design and application

The objectives of WP1 in the first and second 18M-period were related to:

- Development of design concepts for flooding simulations
- Showing the consequences of the different design concepts with regard to building costs and operation
- Verification and demonstration of the use of flooding simulation tools with actually observed data from casualties

The above objectives were mostly covered. Both shipyards carried out their duties in Task 1.1 in the first phase of the project by creating general arrangement plans for the sample ships, creating the corresponding 3D NAPA-databases and by performing damage stability calculations for the sample ships according to SOLAS2009. Deliverables D1.1a and D1.1b were the visible result of task 1.1. The other objectives in WP1, e.g. to improve the flooding behaviour of cruise vessels by analyzing the different concepts with flooding simulation tools, scheduled for the second 18M-period were taken into account in D1.2, where the impact of the findings of this project on new designs has been investigated. As experiences ship designers have been involved the impact on building costs and operation has been considered. Some of the above objectives have also been reached in other Work Packages, e.g. in WP3 and in WP7. Reference has also been made to an alternative, a controlled flooding test reported[2], referred to in WP3, offering a much better basis for research with better control on the parameters involved. Some casualties were also utilized, e.g. the cases that were selected for reference in WP7 (see 3.1.7).

3.1.2 Objectives of Work Package 2 (WP2): Flooding Progression Modelling

The objectives of WP2 in the first 18M-period were related to:

The main objective of this Work Package is to extend knowledge about partitions safety concerning flooding effects. This main objective was split into the following partial objectives in Annex I:

Partial objective 1:

- Obtaining results of leaking and collapsing structures (partitions) by conducting experimental study with the use of new build mock-up test stand

This objective was met during the first period of the project. The commonly agreed, prioritised list of structures to be tested in Task 2.1 and the test plan were created, the test stand was designed, analysed and constructed (Deliverable D2.1a), the structures to be tested were

[2] A common problem in casualty cases, from the researchers point of view, is often the lack of sufficient, accurate enough and easily available data covering all the needs.

delivered within their test frames to CTO, where the tests were carried out. The tests were analysed and, finally, the test report with results was submitted (Deliverable D2.1b).

Partial objectives 2:

- Obtaining results of numerical analyses of leaking and collapsing structures (partitions)
- Development of easy-to-use criteria for the partitions in flooding simulation

The first objective was met in the first period. The second partial objective (i.e. development of easy-to-use criteria for the partitions in flooding simulation) was scheduled for the second 18M-period, when it was met as well (see D2.2b). Numerical analyses were carried out and a report with the results was submitted. Tests with small test samples of materials and tested structures were also included in the Sub-Task 2.2.1 (see D2.2a).

Partial objective 3:

- Evaluating water flow characteristics through various openings by experimental means

This objective was met during the first period. Experimental tests in the test flume were carried out in Task 2.3 with a full sized manhole, and various setups/parts of a model of a cross-flooding duct. A report of all the tests and their results (Deliverable D2.3) was submitted.

Partial objectives 4:

- Evaluating water flow characteristics through various openings by computational means
- Assessing the ventilation effect related with the flow of air inside the inner structure of the vessel)

These objectives were met during the first period. CFD calculations were carried out for a manhole by both CNRS and CTO with different codes, and compared to the experimental results. This little benchmark study showed excellent correspondence between both numerical tools and test results. CNRS also performed CFD calculations for cross-flooding duct both in model scale and in full scale. The results matched well with the experiments and they were reported in Deliverable D2.4a. CTO performed calculations for pressure losses in two typical air pipe arrangements, confirming the second partial objectives 4 in Deliverable D2.4b.

Partial objectives 5:

- Further insight in water flow around and through typical cruise vessel cabin arrangements
- Insight in required level of detail and scale in the modeling of cabin arrangements in flooding simulation programs

Large scale (1:20) model tests were done under atmospheric and scaled air pressure conditions. Two models with a different level of detail were used. Various difficulties were encountered which negatively influenced the measurement accuracy. Despite 3 attempts and various improvements to the setup there seem to be no significant differences between the tests in atmospheric and scaled air pressure. The same applies to the difference between the detailed and more simple model. However, in view of the difficulties encountered this may not be the definitive answer to these questions. The tests and their results were reported in deliverable D2.5b (D2.5a is a draft report, also written, but decleared not to be a public report).

In the second period of the project, due to the circumstances, the focus of the deliverable D2.5c was directed towards lessons learned. The scale and type of the experiments was very unique and although the setup was kept as simple as possible many events were observed that were not expected. Digesting the lessons learned took considerable time and were very worthwhile to report in order not to repeat them in the future.

Partial objective 6:

- Assessing the sensitivity of flooding simulation tools to variations in the input data (discharge coefficients, critical pressure heads, etc.).

This partial objective was scheduled for the second 18M-period, and it was met with the results documented in deliverable D2.6.

The main objective of this deliverable, D2.6, was to utilize the data gathered in the previous tasks of WP2 and to study the effects of variations in the input data on the outcome of flooding in time-domain simulations.

Systematic sensitivity analysis was carried out with three different damage scenarios. The results indicate that the effect on transient heeling in the beginning of flooding is minimal. On the other hand the parameters have notable effect on the time-to-flood. Higher critical collapsing pressure can significantly slow down the flooding process. Also the leakage area ratio has a significant effect on the time-to-flood, especially in a flooding case, where the closed doors do not collapse.

Additionally, the sensitivity of cross-flooding calculations to the applied method for determination of the discharge coefficient for the cross-duct was studied. The results from Task 2.3 and Task 2.4 are used along with the guidelines and regression equations of the IMO Resolution MSC.245(83). The results with experimental and CFD analyses are in perfect agreement. Moreover, the results indicate that the regression equation in the Resolution can significantly under-estimate the cross-flooding time. However, the simple approach for accounting several subsequent openings of the duct provides very similar results to the model test case.

3.1.3 Objectives of Work Package 3 (WP3): Flooding Simulation and Measurement Onboard

The objectives of WP3 were related to:

The development of flood sensors data interpreter for instantaneous use in flooding prediction tools, as well as to derive methods for assessment of uncertainty in such data interpretation or for resolution of conflicts with alternative data acquisition methods (e.g. verbal description by the crew). Development of guidelines on principles for design of flooding monitoring systems compatible with numerical simulation tools belong to these objectives. All of the above objectives (for WP3) were mainly scheduled to be attained in the second 18M-period.

The objectives of WP3 were met. Most of the work concentrated on the development of a flood sensor data interpreter and a novel approach for predicting progressive flooding in time-domain. The developed method is very fast and provides valuable information for decision support onboard a flooded ship. The results of WP2 can be directly utilized in the flooding prediction tool. The developed method has been tested against both full-scale measurements and a well-validated time-domain flooding simulation tool. The effect of waves was studied in Task 3.2, providing further support for the adopted simplification of quasi-stationary ship motions in the flooding prediction onboard.

Based on the observations and new information, gathered in different WPs, a proposal for guidelines on the requirements for flooding detection sensors and their placement in passenger ships was developed (Deliverable D3.3). Hopefully these guidelines will soon be submitted to IMO for further consideration.

3.1.4 Objectives of Work Package 4 (WP4): Stochastic ship response modelling

The objectives (for WP4) were mainly scheduled to be attained in the second 18M-period, so an assessment on how well they were met, is possible, now at the end.

The overall objectives of WP4 were to establish requirements and uncertainty bounds on methods for prediction of the time it takes a ship to capsize or sink after damage. The requirements must list and categorise importance of key variables to be accommodated by the methods used, e.g. how the damage is described, is the wind effect accounted for, how accurately is the wave impact represented, how is ship manoeuvrability accounted for, how to address geographical location, etc. The requirements must also put forward uncertainty bounds to be assigned to such methods and input variables.

The objectives have been met by the end of the project. The process of derivation of an analytical model for prediction of time to capsize after flooding has been documented. Comprehensive explanation has been given on the relation between ship stability, some regulatory instruments and the stochastic process of stability deterioration. Validation and sensitivity studies have been undertaken, followed by case studies to demonstrate applicability. The uncertainty has been quantified, and a number of key variables pointed out.

3.1.5 Objectives of Work Package 5 (WP5): Rescue process modelling

The objectives of WP3 were related to:
Establishing requirements and uncertainty bounds for models of mustering, abandonment and rescue operations. The requirements must specify the degree of realism of the foundering process required to be accounted for in prediction of vessels evacuability, the detail of representation of rescue operations, etc. The requirements must also put forward uncertainty bounds to be assigned to such methods. The objectives (for WP5) were mainly scheduled to be attained in the latter 18M-period. In WP5, all remaining deliverables, D5.2-D5.5, were delivered and the objectives were fairly well covered.

3.1.6 Objectives of Work Package 6 (WP6): Standard for decision making in crises

The overall objectives of WP6 were to establish an integrated standard for decision making, reflecting in a balanced manner the societal concerns pertinent to a "large" loss. The proposed procedure reflects the considerable uncertainty not resolvable with today's technology, human element and judgement in crises, as well as the knowledge on stochastic nature of ship stability deterioration process. The decision making process is complex, however the proposed criterion and steps are straightforward, auditable and mirrors a common sense reflection on reality of circumstances known to occur in crises. In addition an advanced procedure for maintaining preparedness at all times have been derived, and tested in real life environment.

3.1.7 Objectives of Work Package 7 (WP7): Demonstration

The main objective of WP7 is to test within working environment the effectiveness of the standard in rating different decisions for various casualty cases for a series of hypothetical as well as real-life (historical) scenarios as well as test the approach in the design process. The results will provide feedback to other work packages for modification, improvements or fine-tuning of the proposed standard. The above objectives for WP7 were mainly scheduled to be attained in the latter 18M-period. The following deliverables were produced: Partial deliverable D7.2a, partial deliverable D7.2b (combined under one cover document, D7.2) and deliverable D7.3.

The aim of testing the FLOODSTAND approaches in view of the mitigation of the casualty risk of passengers onboard ships associated with the ship flooding hazard. The testing was understood to be made within laboratory environment, as the same portable computers can be used in . The two developed approaches of FLOODSTAND, to be tested, were those of the "FLOODSTAND for crisis management", as elaborated in WP4-6, and the "FLOODSTAND for flooding control" approach, as elaborated in WP1-3. The conducted studies with the former approach demonstrated that the results could be assumed as well correlated to the reported findings from the corresponding accident investigations (Estonia & Monarch; therefore they proved satisfactory for the developers (SSRC, BMT). However, due to the large uncertainty related to the detection of the damage extent, the onboard prediction with the same approach remains accordingly of limited confidence.

The "FLOODSTAND for flooding control" approach was tested by NAPA (Task 7.2), as implemented with the NAPA-Onboard software, and was used to analyze the flooding of two grounding casualties for one cruise ship, as they were defined in D7.1. The tests assumed some off-board setup (i.e. without estimations for the damage case/extent) for training purposes, and the collected results were to the satisfaction of the developers (NAPA). The method might be extended by exploiting additional information from water detection measurements, however it was not demonstrated. The consequences to the damage stability because of specific ship flooding could be computed with the tested tool, and awareness to the training crew could be provided. This was demonstrated with the impact of watertight doors on the sinking of the damaged cruise vessel. The time performance of the flooding prediction tool needs still some improvement. The graphical user interface may improve functionality of the tool however contributes further to the computational requirements. The detailed work was reported with the deliverable D7.2b.

Thus, it can be considered that the objectives for WP7 and the whole project were fairly well covered.

4. Work progress and achievements during the reporting period (1.9.2010-29.2.2012)

4.1 WP1 Design and application (WP-leader: STX)

Task 1.2 Analysis of the real flooding effects on design (Responsible: STX, Participants: MW, DNV, AALTO)

In this task the applicability of the findings of other work packages, mainly WP2, on the design of modern cruise ships was investigated. Consideration was used to take the advantage of most of the results of the other work packages, however. Main focus was laid on the results of the full scale flooding tests and simulation work of WP2, but also the design targets presented in WP6 have been considered.

It was shown, that the results found in these work packages do not have a significant influence on the global design of cruise ships, as many of the assumptions defined in the explanatory notes of SOLAS could be confirmed in this project. However,

- the results obtained in project FLOODSTAND give more precise input data and thus, more reliable basis for time domain flooding simulations used for stability studies and assessments.
- Significant details in the design of the watertight subdivision of cruise ships can now be improved to enhance safety and to consider the physical behavior of the ship.
- A number of items have been identified, which need to be addressed to the Regulatory Bodies to improve the SOLAS convention and its explanatory notes.
- No remarkable deviations from Annex I occurred;

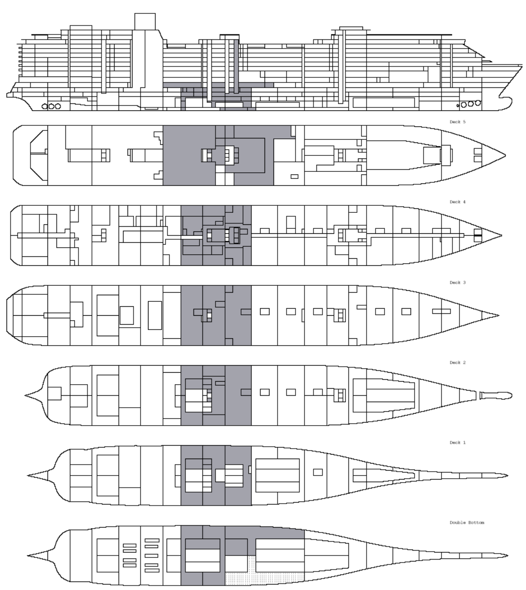

Figure 1 Damage case; instantaneous cross-flooding in large DB dry tank (Source: Deliverable D1.2)

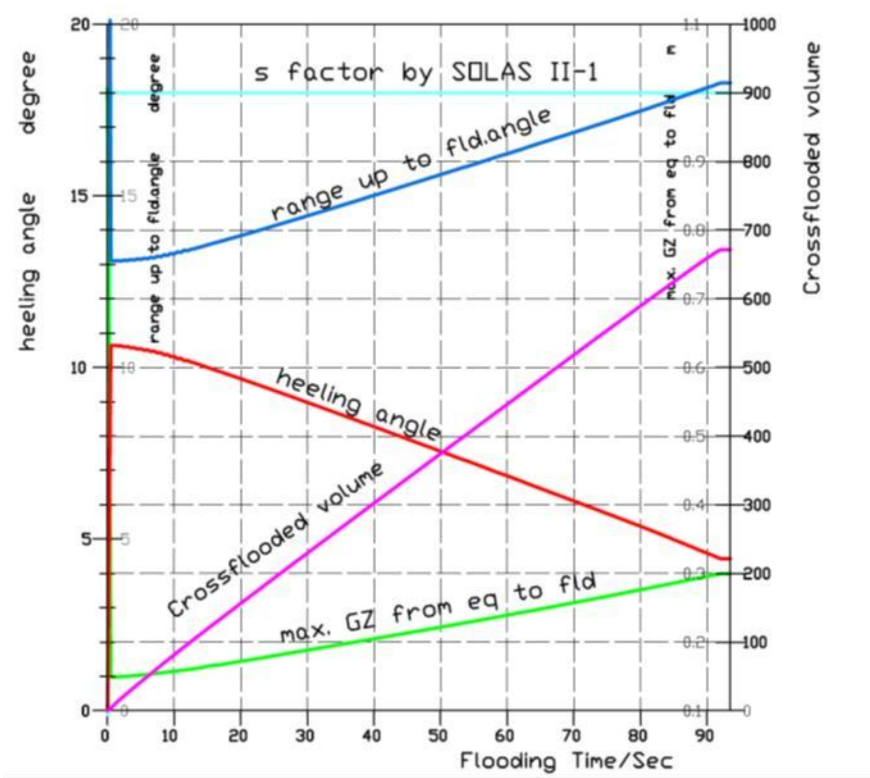

Figure 2 Floating position and s-factor during instantaneous cross-flooding (Source: Deliverable D1.2)

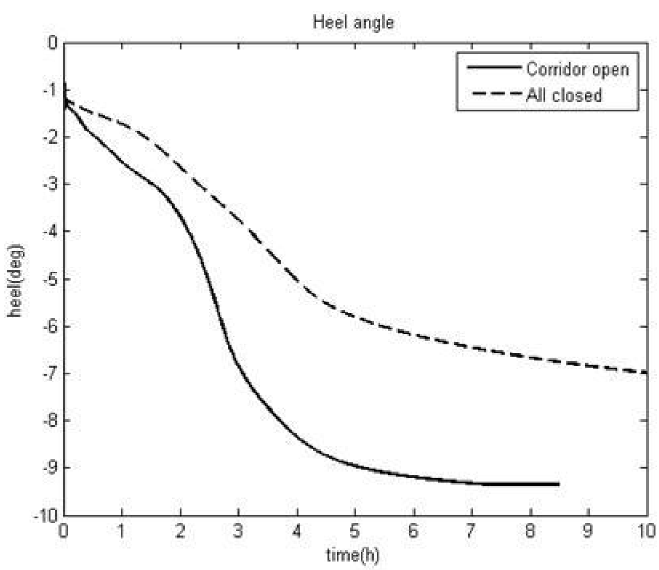

Figure 3 Effect of the status of fire doors on bulkhead deck: Change of heel angle in another damage case, with the service corridor doors open (solid line) and with all service corridor doors closed (dashed line). (Source: Deliverable D1.2)

Deliverable D1.2 was published in this second 18-month period of the project.

Scientific publications (list):

- Jalonen, R.P.S., Jasionowski, A., Ruponen, P., Mery, N., Papanikolaou, A., **Routi, A.L.**, (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

- Jalonen, R., Ruponen, P., Jasionowski, A., Maurier, P., **Kajosaari, M.**, Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

4.2 WP2 Flooding progression modelling (WP-leader: AALTO)

Task 2.1 Experiments with leaking and collapsing structures (Responsible: CTO; STX, MEC, MW, AALTO)

In WP2, the first task, T2.1, was divided in two sub-tasks:

Sub-Task 2.1.1 Design of the test stand for static pressure loading of the ship structure mock-ups (e.g. walls with cabin, fire doors or SWT-doors)

This sub-task was discussed in deliverable D0.4a.

Sub-Task 2.1.2 Experiments (Responsible: CTO)

This sub-task was also discussed in deliverable D0.4a.

- Significant results attained so far in this task (T2.1):

- Test methodology developed
- Test stand/mock-up
- Test results of the unique destructive tests carried out
- Two deliverables produced (in the first 18-month period): D2.1a and D2.1b

- A short overview of T2.1 was introduced to IMO in SLF53 in January 2011 (together with an overview of project FLOODSTAND and some other results of the project).

Task 2.2 Numerical modeling and criteria for leaking and collapsing structures (Responsible: MEC)

In WP2 the second task T2.2, with the above title, was divided in two sub-tasks, the first of which, Sub-Task 2.2.1, was scheduled for the first half of the project. The second sub-task, Sub-Task 2.2.2, was scheduled to be started after the end of the previous sub-task.

Sub-Task 2.2.1 Numerical studies and analysis of leaking and collapsing structures (Responsible: MEC, Participants: CTO)

This sub-task was also discussed in deliverable D0.4a.

Sub-Task 2.2.2 Development of easy-to-use criteria for the flooding simulation (Responsible: STX, Participants: CTO, MEC, MW, NAPA, AALTO)

Based on the experiments and the finite element simulations in Sub-Task 2.1.2 and in Sub-Task 2.2.1, the estimated risk criteria of leakage and collapse of doors and other structural elements will be proposed. This was done in deliverable D2.2b, published during the second 18-month period of the project.

- Significant results attained in this task (T2.2) :

- The guidelines in D2.2b were developed. They were based on the results of the experimental tests in Task 2.1 and of the numerical analysis in Sub-Task 2.21. Results from the laboratory tests carried out by MEC and published in deliverable D2.2a.

- A short overview of T2.2 was introduced to IMO in SLF53 in January 2011 (together with an overview of project FLOODSTAND and some other results of the project).

- The results of collapse/leakage pressure heads of non-watertight doors to simulate flooding of water through fire-rated doors along bulkhead deck have already been used in real ship design within the industry

Definition	Action/Performance	Description	Conditions of use
Watertight	To withstand constant pressure[2] ($p > p_L$)	Under bulkhead deck	To be kept closed during navigation (special exceptions may be applied)
Light watertight	To withstand constant water pressure[3] ($p < p_L$)	On Bulkhead deck	To be kept closed during navigation (special exceptions may be applied)
Semi Watertight	Weathertight to provide positive residual stability[4]	On bulkhead deck and above	May be kept open during navigation

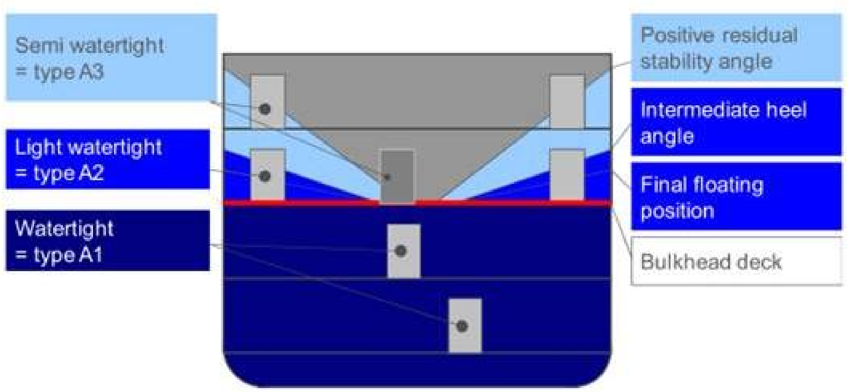

Figure 4 Category A doors in passenger ships
(Source: STX Finland, *used in Deliverable D1.2)*

Task 2.3 Experimental studies on pressure losses (Responsible: AALTO, Participants: STX, MW)

This task was carried out during the first 18-mont period of the project and it was discussed in deliverable D0.4a. However, some actions related to it could be recognized in relation to scientific publications and to reports to IMO (SLF53 & SLF54)

• Significant results attained in this task (T2.3) during the second 18-month period:

- The journal paper related to these tests has been published in *Ocean Engineering (Stening et al, 2011)*
- A journal paper related to cross-flooding has been published in *Ocean Engineering (Ruponen et al, 2012)*
- A short overview of the tests in T2.3 was included in a general presentation of the project FLOODSTAND, too, in the 11th International Ship Stability Workshop in Wageningen, The Netherlands, in June 2010

Task 2.4 Computational studies & RANSE CFD (Responsible: CNRS, Participants: STX, CTO)

This task was carried out during the first 18-month period of the project and it was discussed already in deliverable D0.4a.

• Significant results attained in this task (Task 2.4):

- A journal paper related to cross-flooding has been published in *Ocean Engineering (Ruponen et al, 2012)*

Task 2.5 Model tests for cabin areas (Responsible:MARIN, Participants: STX, MW, NAPA)

This task was carried out during the first 18-month period of the project and it was discussed in deliverable D0.4a.

• Significant results attained in this task (T2.5):

- The lessons learned from the model tests are listed in the report and are valuable results as such
- An other remarkable result is the experience from special model tests of this particular type that they proved to be even much more complicated than originally foreseen. The test type and the environment, in which the model tests were carried out, form together an extremely challenging combination
- Deliverable 2.5c was published during this period

Task 2.6 Sensitivity of simulation model (Responsible: AALTO, Participants: NAPA)

This task was scheduled to be started in the second 18-month period of the project, because of the need for results from the previous tasks in this and the previous WPs (WP1 and WP2). Therefore, the research related to this task will be carried out mainly during the second 18-month period.

- Significant results attained in this task (T2.6):

- In the studies (reported in D2.6), no parameter variation whatsoever seemed to have any significant effect on the maximum transient heel[3] in the beginning of the flooding

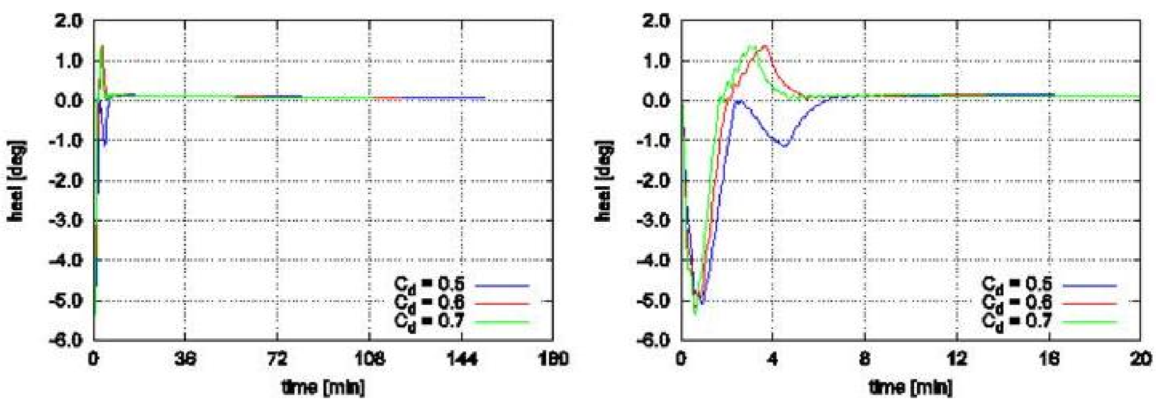

Figure 5 Time history of heel with different discharge coefficients (Source: Deliverable D2.6)

- The applied parameters had notable effects on the time-to-flood and on the progress of flooding and the heeling after the transient phase. For example, variation of discharge coefficient affected directly the flooding time and indirectly the collapses of doors

- Variation of critical pressure head for collapse had the most apparent effect on the way the flooding progressed. In this way it affected the nature of the heeling behaviour, but it also had an effect on the flooding rate and thus on the time-to-flood

- Leakage area modelling had a clear effect on the time-to-flood. This effect became apparent after the early flooding phases when most of the flooding was based on leaking through closed doors. If the variation of A_{ratio} did not have an effect on the collapse of doors, the consequent effects especially on heel were almost non-existent

- In a flooding case, where most of the flooding is leaking through closed doors the applied leakage area ratio seemed to have a significant effect on the time-to-flood. E.g. underestimation by 50% can lead to up to 50% overestimation in the time-to-flood. However, the effects on the behaviour of flooding (e.g. order of flooded compartments) were minimal. Thus, the conservative approach is to use slightly too large leakage area ratios in order to avoid the over-estimation of time-to-flood

[3] The transient heel angle at the beginning of the flooding may become very important if it can cause excessive transversal shift of heavy items onboard introducing a constant list of the ship or if it may act as a cause of additional (and consequently progressive) flooding through some openings above waterline.

- Based on the presented studies, it seems to be well justified to use the industry standard discharge coefficient 0.6 for all openings, except the pipes and cross-flooding devices. Based on the CFD and model tests in Tasks 2.3 and 2.4 of the FLOODSTAND project, this value is very realistic

- The simplified formula for calculation of cross-flooding time, MSC.245(83) provides very similar results as detailed time-domain flooding simulation. However, the effective discharge coefficient for the duct should be determined with Eq. (7)[4] or with CFD since the use of the regression Eq. (6)[3] results in significantly too fast cross-flooding times

- One task of next SDS Correspondence group is to update draft amendments to the Recommendation on a standard method for evaluating cross-flooding arrangements (resolution MSC.245(83) and review equations 2.4 and 2.5 of the annex and figures 13 and 14 shown in the appendix 2 of the Recommendation. This review of MSC. 245(83) is based on the results received from project FLOODSTAND (and reported to IMO in SLF54/4

- Deliverable D2.6 was published during this 18-month period

Scientific publications of WP2:

- **Jalonen, R.P.S.**, Jasionowski, A., Ruponen, P., Mery, N., Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

- **Stening, M., Järvelä, J., Ruponen, P., Jalonen R.**, (2010), Determination of discharge coefficients for a cross-flooding duct, Ocean Engineering, Vol. 40 (2012), pp. 27–39

- **Ruponen, P., Queutey, P., Kraskowski, M, Jalonen, R., Guilmineau, E.** 2012a. On the calculation of cross-flooding time. Ocean Engineering Vol. 40, 27-39

- **Jalonen, R.**, Ruponen, P., Jasionowski, A., Maurier, P., Kajosaari, M., Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

More scientific papers from WP2 are expected …

[4] in deliverable D2.6

4.3 WP3 Flooding Simulation and Measurement Onboard (WP-leader: NAPA)

In Task 3.1: Development of flood sensors data interpreter, a new inverse method for definition of flooding and damage extents based on flood level sensor data has been developed and documented. The accuracy of the method has been verified against accurate time domain simulation and even full scale test and the results were found good. However, the calculation took too much time to be able to apply for use on board ships.

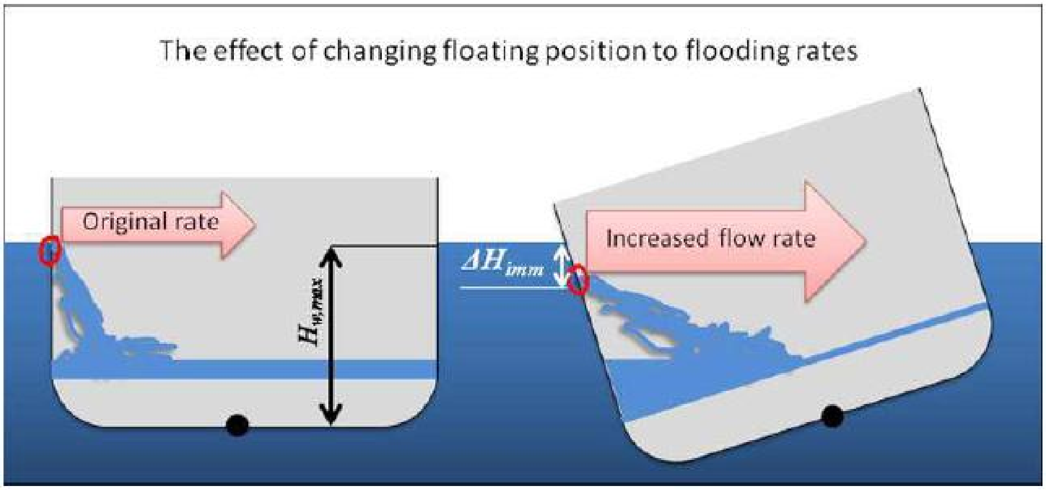

Figure 6 The effect of changing floating position on the flooding rate through the breach (Source: Deliverable D3.1)

Improved method for prediction of progressive flooding has been developed and reported. Computational performance has significantly improved from the initially used time-domain simulation without significant sacrifice of accuracy. This method forms a solid basis for decision making applications to be used on board ships.

In Task 3.2: Impact of ship dynamics, a new approach on calculation of the motions of a damaged ship has been developed by combining NAPA and LAIDYN software.

In Task 3.3: Design of flood sensor systems, a guideline for design of flood sensor systems to be used for decision making systems has been developed. The guideline discusses the type, required number and location principles of flood water sensors to achieve sufficient accuracy of the flooding prediction calculations (Task 3.1).

Significant achievements in WP3 were:

In Task 3.1: Development of flood sensors data interpreter: Computational performance and accuracy of the improved method for prediction of progressive flooding has reached acceptable level for analysing of real time accident scenarios. This method forms a solid basis for decision making applications to be used on board ships.

In Task 3.2: Impact of ship dynamics: Combining NAPA and LAIDYN software makes it possible to take into account the effect of sea state in the flooding prediction calculations. After some further development, this can be integrated into the decision making system to be used on board ships.

In Task 3.3: Design of flood sensor systems: A clear guideline for design of flood sensor systems makes it easier for the shipyards and ship owners to define the required level of instrumentation needed for successful application of flooding prediction calculations. The guideline forms a solid basis for further discussion at IMO targeting to revised requirements for passenger ships.

Deviations observed and corrective actions taken:

- All tasks were completed within time and resource allocations
- Task 3.3 was started slightly behind schedule, but due to the efforts from all task participants (NAPA, STX, RTR and DNV), the report was finished in time, without any effect on the scope of work.
- All tasks were completed within time and resource allocations[5]

Publications:

Deliverables D3.1, D3.2 and D3.3 were published during this 18-month period.

Scientific publications (list):

- Penttilä, P., Ruponen, P. (2010), Use of Level Sensors in Breach Estimation for a Damaged Ship. Proceedings of the 5th International Conference on Collision and Grounding of Ships ICCGS, June 14th - 16th 2010, Espoo, Finland, pp. 80-87.

- Jalonen, R.P.S., Jasionowski, A., **Ruponen, P.**, Mery, N., Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23
- **Manderbacka, T.L.**, **Matusiak, J.E., Ruponen, P.T.** (2011) Ship Motions Caused by Time-Varying Extra Mass on Board. Proceedings of the 12th International Workshop on Ship Stability, Washington, D.C. USA - 12-15 June 2011, pp. 263-269.

- Jalonen, R., **Ruponen, P.**, Jasionowski, A., Maurier, P., Kajosaari, M., Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

[5] With the only modification of a shift of some person-months of NAPA from WP3 to WP7, with no change to the total efforts or results (Note! This change was based on the earlier agreement in the assembly meetings in Gdansk & Paris discussed and agreed between the P.O. and the Coordinator, too). The additional partial deliverable D7.2b was the result of this part of the work that was just change from one WP to another with no effects on the contents of the work or the schedules.

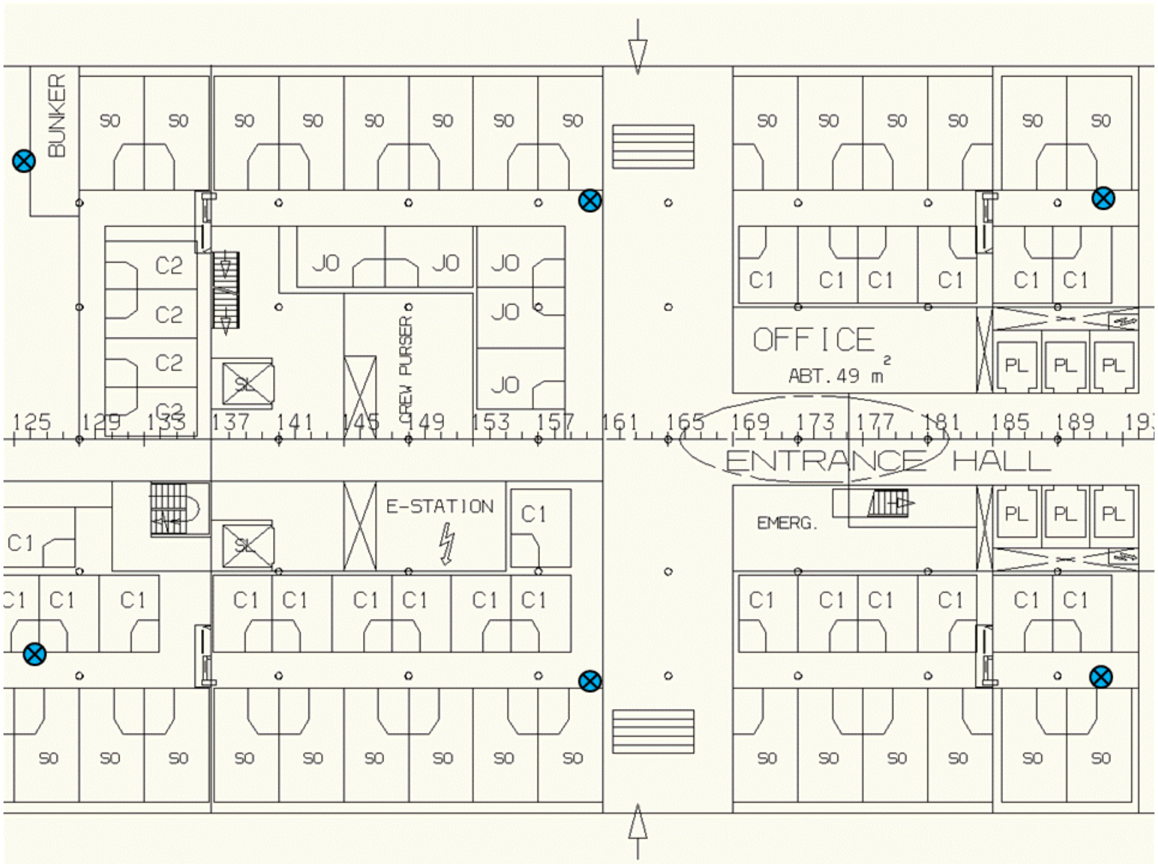

Figure 7 Sensors above bulkhead deck (Source: Deliverable D3.3)

4.4 WP4 Stochastic ship response modelling (WP-leader: SSRC)

- A summary of progress towards objectives:

Analytical model for prediction of the time to capsize after flooding has been derived as follows.

$$F_{cap}\left(t|Hs\right)=1-\left[1-\Phi\left(\frac{Hs-\left(H_{crit}-\varepsilon\right)}{0.061\cdot\left(H_{crit}+\varepsilon\right)}\right)\right]^{\frac{t}{t_0}}$$

$$H_{crit}=4\cdot\left(\frac{GZ_{\max}}{0.25}\cdot\frac{Range}{25}\right),\ t_0=30\,\text{min}\ ,\ \varepsilon=10^{-12}$$

Extensive discussion on the relationship between ship stability, legislative methods available and the process of ship stability deterioration observed in experiments have been presented. Based on an extensive validation studies for RoRo passenger type ships the model seems to be adequate to represent survivability for any type of hull damage of such ships which results in a known flooding extent, thus narrowing down information needed for quantitative assessment of time available before capsize.

Considering sensitivity to input information, especially concerning the extent of flooding, it is proposed that even though core validation study is performed for a RoPax ship case only, the proposed method may be applied to any type of vessel, e.g. cruise ships, as the key functionality of the solution is differentiation between completely survival and non-survival states valid equally for any ship, and despite the fact that some conservatism deriving from epistemic uncertainty pertaining to the model may be expected.

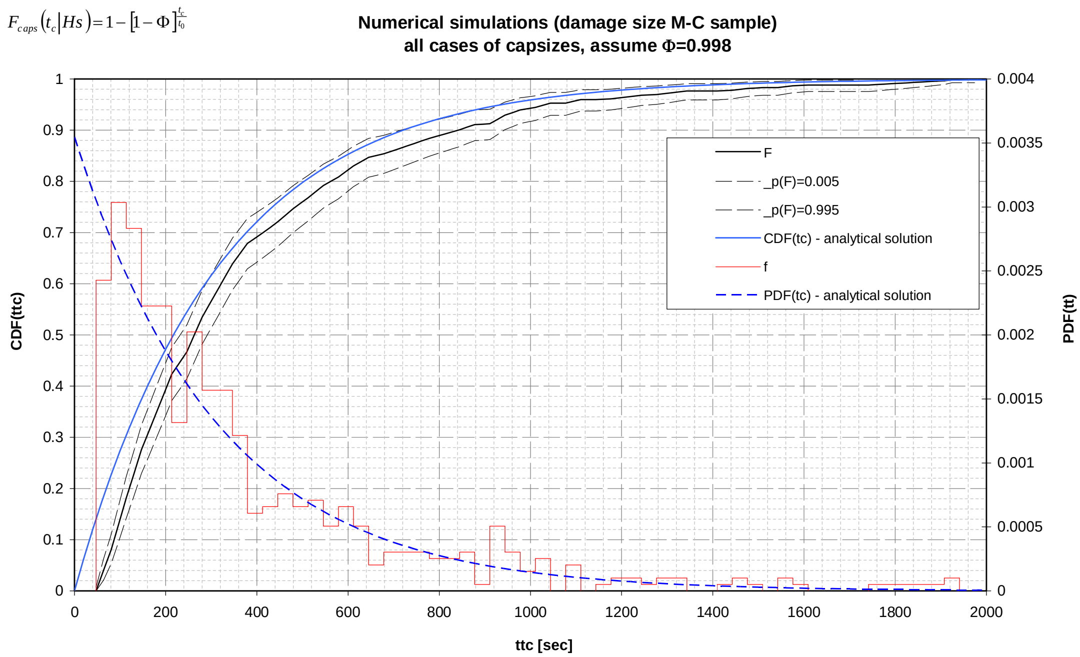

Figure 8 Results of numerical simulations of the distribution of ttc, Time to Capsize (Source:A. Jasionowski: Presentation in the final Workshop/Seminar of project FLOODSTAND, in Espoo 7.2.2012, available 25.2.2012 at: "http://floodstand.aalto.fi/Info/examples/final_workshop.htm")

The uncertainty analysis indicated that the **extent of flooding,** affecting parameters of GZ_{max} and Range, seems to be one of the most critical information needed for confident assessment of criticality of flooding situation. The precision or lack thereof in estimating the extent of flooding experienced during crises seems to be an overriding uncertainty datum, on the basis of which the epistemic uncertainties of the modelling itself should be considered acceptable for engineering purposes of decision making during crises

A hybrid model of ship stability deterioration process, combining numerical simulations with analytical projections, was developed based on Bayesian inference framework.

$$F_{T|\Phi}\left(t_c|\varphi(t)\right)=\sum_i \frac{p_D(d_i)\cdot F_{\Phi|D}\left(\varphi(t)|d_i\right)}{\sum_j p_D(d_j)\cdot F_{\Phi|D}\left(\varphi(t)|d_j\right)}\cdot F_{T|D\&\Phi}\left(t_c|d_i \cap \varphi(t)\right)$$

A case study indicated that little or no enhancement on projections of the situation evolution can be attained during crises through observing ship angle of heel.

This result implies that judgements based on perceptions or measurements of angle of heel might be misleading in both directions, (a) when an angle of heel is observed it might not mean that the situation is critical and (b) when no angle of heel is observed might not imply that the situation is "safe". It must be noted, however, that these observations are based on only small sample of numerical experiments, and that therefore further studies are needed to understand better the nature of inferences that can be drawn from real-life information during evolving crises.

Therefore, any assessment must strive to minimise the uncertainty (predominantly the extent of flooding) to minimum and methods, perhaps such as derived in this project, must be used for systematic judgement on criticality of the situation rather than rely on subjective judgement of the crew.

These conclusion could not have been obtained readily based on pure numerical simulations, model experiments or pure analytical solutions, and hence the hybrid modelling proves to add value to studies on the process of stability deterioration after flooding.

Main achievements:

- All model test results with the model of Estonia, from Task 4.1, Part a, Part b and Part c are now available and reported in D4.1
- Demonstrated the reliability of numerical simulations (WP4)
- Identified robust modeling principle for use in any decision support system
- An analytical model for ttc was developed
- A hybrid model of ship stability deterioration process, combining numerical simulations with analytical projections, was developed
- All deliverables were finally produced

Publications:

Deliverables D4.1, D4.2, D4.3, D4.4 and D4.5 were published.

Scientific publications (list):

- **Spanos, D.A., Papanikolaou, A.D.**, On the Time Dependent Survivability of ROPAX Ships, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23
- Jalonen, R.P.S., **Jasionowski, A.**, Ruponen, P., Mery, N., Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23
- **Qi Chen, Jasionowski, A,** "A New Methodology for Modelling Stochastically the Time to capsize", 4th International Maritime Conference on Design for Safety, October 18-20, 2010 in Trieste, ITALY.
- Jalonen, R., Ruponen, P., **Jasionowski, A.**, Maurier, P., Kajosaari, M., Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

4.5 WP5 Rescue process modelling (WP-leader: BV)

• A summary of progress towards objectives:

Task 5.1 Benchmark data on mustering/abandonment/rescue

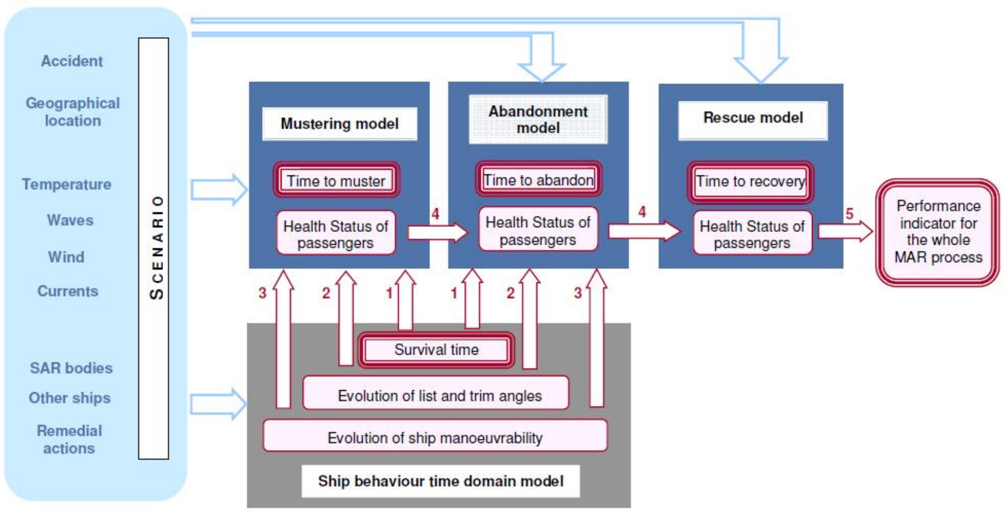

Figure 1 A schematic view of the M-A-R model to be developed in WP5 (Source: Deliverable D5.1)

Task 5.1 has been finalised and the work is described in the previous periodic report. The complete draft version of the corresponding deliverable D5.1 was submitted to the coordinator within the scheduled time (i.e. project Month 24). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.1 was published on the public web site of FLOODSTAND on 15.3.2010.

Task 5.2 Test/develop mustering (M) model

Tasks 5.2, 5.3 and 5.4 have exactly the same architecture. Therefore, the activities performed in Tasks 5.2, 5.3 and 5.4 are run in common.

Sub-task 5.2.1: Refine scenarios

This sub-task is completed. The data concerning the two demonstration cases were gathered concerning the type and number of Life-Saving Appliances, their characteristics (capacity and internal arrangement), the characteristics of the means of rescue used, etc.).

Sub-task 5.2.2: Define main obstacles, phenomena, and significant parameters

This sub-task is completed. A final consolidated list of obstacles for the Mustering phase has been agreed between partners. The significant parameters of the models for assessing those obstacles have been defined.

Sub-task 5.2.3: Define analyses to be performed

This sub-task is completed. The tools that have been used to perform the analysis have been defined. Scenarios (list angles, time of day…) have all been listed.

Sub-task 5.2.4: Develop one model

This sub-task is completed. All simulations have been carried out on the software Evi by SSRC. Time to Muster for both reference ships and for all scenarios been calculated.

Sub-task 5.2.5: Test the model

This sub-task is completed. Results have been developed in Deliverable 5.5.

Task 5.2 has been finalised. The complete draft version of the corresponding deliverable D5.2 was submitted to the coordinator with a delay on the schedule (on the 9^{th} of November 2011). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.2 was published on the public web site of FLOODSTAND on 03.01.2012.

Task 5.3 Test/develop abandonment (A) model

Sub-task 5.3.1: Refine scenarios

This sub-task is completed and was carried out together with Sub-task 5.2.1 (see above).

Sub-task 5.3.2: Define main obstacles, phenomena, and significant parameters

This sub-task is completed. The obstacles associated to the Abandonment phase were listed, the phenomena to be modelled in order to assess their influence were identified.
The relevance and significance of the obstacles were discussed by all partners.
A final consolidated list of obstacles for the Abandonment phase has been agreed between partners. The significant parameters of the models for assessing those obstacles have been defined.

Sub-task 5.3.3: Define analyses to be performed

This sub-task is completed. The tools that need to be use to perform the analysis have been defined. Parameters influencing each obstacle have all been listed.

Sub-task 5.3.4: Develop one model

This sub-task is completed. A model has been developed for each obstacle and each EU FP6 Safecrafts project result that can be reused has been adapted to FLOODSTAND scenarios and reference ships. All matrices associated with each obstacle have been calculated.

Sub-task 5.3.5: Test the model

This sub-task is completed. Results have been developed in Deliverable 5.5.

Task 5.3 has been finalised. The complete draft version of the corresponding deliverable D5.3 was submitted to the coordinator with a delay on the schedule (on the 9th of November 2011). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.3 was published on the public web site of FLOODSTAND on 03.01.2012.

Task 5.4 Test/develop rescue (R) model

Sub-task 5.4.1: Refine scenarios

This sub-task is completed and was carried out together with Sub-task 5.2.1 (see above).

Sub-task 5.4.2: Define main obstacles, phenomena, and significant parameters

This sub-task is completed. The obstacles associated to the Rescue phase were listed, the phenomena to be modelled in order to assess their influence were identified.
The relevance and significance of the obstacles were discussed by all partners.
A final consolidated list of obstacles for the Rescue phase has been agreed between partners. The significant parameters of the models for assessing those obstacles have been defined.

Sub-task 5.4.3: Define analyses to be performed

This sub-task is completed. The tools that need to be use to perform the analysis have been defined. Parameters influencing each obstacle have all been listed.

Sub-task 5.4.4: Develop one model

This sub-task is completed. A model has been developed for each obstacle and each EU FP6 Safecrafts project result that can be reused has been adapted to FLOODSTAND scenarios and reference ships. All matrices associated with each obstacle have been calculated.

Sub-task 5.4.5: Test the model

This sub-task is completed. Results have been developed in Deliverable 5.5.

Task 5.4 has been finalised. The complete draft version of the corresponding deliverable D5.4 was submitted to the coordinator with a delay on the schedule (on the 29th of November 2011). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.4 was published on the public web site of FLOODSTAND on 03.01.2012.

Task 5.5 Uncertainty bound

The scope of this task have been slightly shifted from original plan as uncertainty bound were difficult to assess due to the generic nature of the models developed in this work package, more information about this change can be found in the Deliverables.

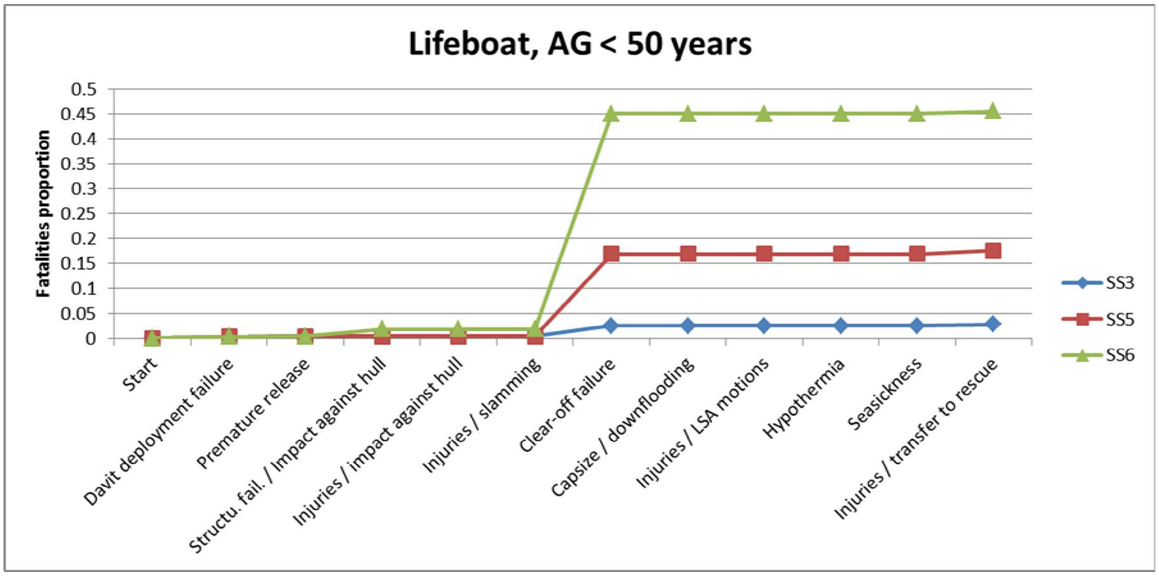

Figure 2 Expected casualties through the MAR process, influence of sea state, Lifeboat, <50 year old group (Source: WP5 Presentation in the Final Public Workshop of project FLOODSTAND)

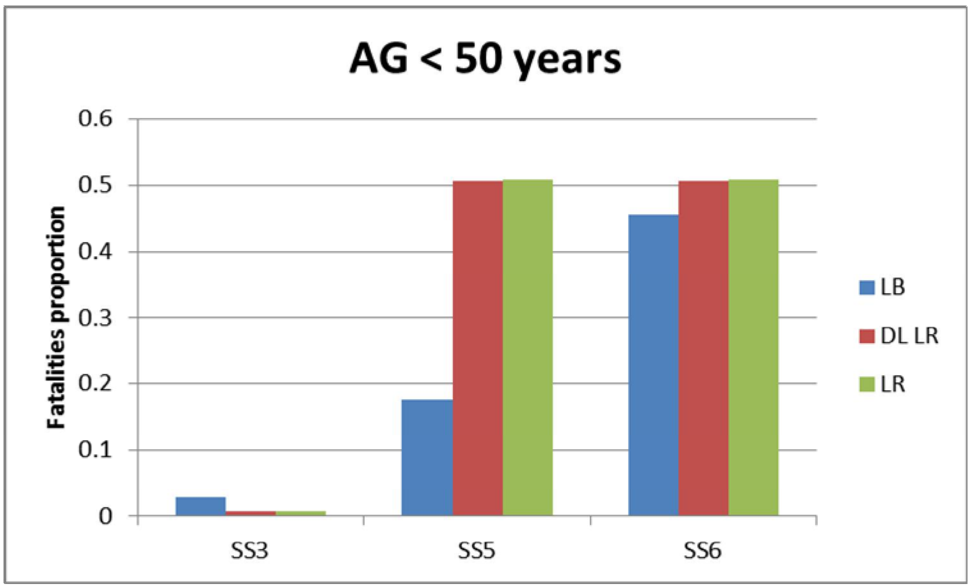

Figure 3 Expected casualties through the MAR process, influence of LSA type, <50 year old group
(Source: WP5 Presentation in the Final Public Workshop of project FLOODSTAND)

The main goal of the task 5.5 was to assess the MAR process as a whole using the results from all previous tasks as well as the software "Casualty calculator", developed by BMT (described in deliverable D5.2).

This task 5.5 has been finalised. The complete draft version of the corresponding deliverable D5.5 was submitted to the coordinator with a delay on the schedule (on the 1st of February 2012). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.5 was published on the public web site of FLOODSTAND on 14.02.2012.

WP5 Technical coordination

• Significant results in WP5:
- A list of obstacles has been defined.
- All obstacle matrices have been calculated
- Several key parameters have been derived from WP5 results that have a significant influence on the expected number of casualties.

WP5 deliverables:

Deliverable D5.1 with three annexes was issued in the previous 18-month reporting period.

Deliverables D5.2, D5.3, D5.4 and D5.5 were delivered in the final, second 18-month reporting period.

Publications of WP5:

WP5 presentation in the Final Public Workshop of project FLOODSTAND, January 2012, Aalto University, Espoo, Finland

Scientific publications (list):

• Jalonen, R.P.S., Jasionowski, A., Ruponen, P., **Mery, N.**, Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23

• Jalonen, R., Ruponen, P., Jasionowski, A., **Maurier, P.**, Kajosaari, M., Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

4.6 WP6 Standard for decision making in crises (WP-leader: SSRC)

- A summary of progress towards objectives in WP6:

Models for loss function and likelihood functions have been proposed, and an integrated format of decision making process addressing ship's residual stability, the abandonment and the rescue operations, as well as dominant inherent uncertainties have been proposed, as follows:

Step 1 - Order mustering and follow with situation assessment at the first sign of distress
Step 2 - If flooding extent not determinable or escalating then abandon

Step 3 - Else if [$\min(0.125 \cdot Hs, 1) \cdot < F_{cap}(3hrs|Hs)$] then abandon

Step 4 - Else stay onboard

Some fundamental uncertainties related to the assessment of the extent of flooding do not seem resolvable at present, and given considerable level of typical ship vulnerability to flooding with possible rapid capsize, it is recommended in the above process that the order to muster is an automatic and immediate crew reaction to first report or a sign that distress occurs. During the mustering time all efforts to assess the extent of flooding must be made, and in case doubts remain as to the scenario, or in case the flooding is escalating, an order to abandon should be given. In case flooding situation is well established, a quantitative criterion is given to make judgement on the risk balance between decisions of abandonment and staying onboard.

Naturally, the above process is susceptible to subjective interpretations as to what constitutes "doubt" or "well established" situation awareness, and these are proposed to remain discretionary judgements of the crew.

It follows that technologies (better sensors, their denser distribution and good maintenance) and procedures for monitoring of all of ship spaces should be developed, so that this fundamental uncertainty is resolved. However the proposed above procedure would seem competent and generic independent of the state of technology.

The process highlights the important decision making elements, which when used in training may allow the crew to better understand importance of their preparedness for handling crises.

Assessment of the likelihood function is proposed to be adopted for any type and size of the vessel, even though its key validation was performed for RoPax type ships only, as the formulation is based on generic parameters of residual stability, as well as generic assumptions on the impact of the process of floodwater progression ("GZ cut-off at down-flooding points"), with the latter mitigating the mentioned expected uncertainties of situation assessment.

Additionally, a mathematical model for an instantaneous stability monitoring paradigm has been proposed, facilitating efficient upkeep of crew preparedness for handling crises, should these occur. Such preparedness is possibly the most effective means of handling crises or its prevention in the first place.

The proposed prototype of the standard seems robust and reflective of the identified physics prevailing during flooding, loss of stability and abandonment, as well as the state of today's infrastructure available for establishing ship's status.

WP6 deliverables:

Deliverables D6.1 and D6.2 were issued within a broad definition of this second 18-month reporting period. The original delivery time of D6.1 in project month 18 was postponed to project month 30, until all the data and theories have been carefully analyzed.

Publications related to WP6:

Deliverables D6.1 and D6.2 were published.

Scientific publications (list):

- Jalonen, R.P.S., **Jasionowski, A.**, Ruponen, P., Mery, N., Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.
- Jasionowski, A., (2010), Decision Support for Crises Management and Emergency Response, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.
- Jasionowski, A, "Decision Support for Ship Flooding Crisis Management", Journal of Ocean Engineering, (submitted in September 2010).
- Jalonen, R., Ruponen, P., **Jasionowski, A.**, Maurier, P., Kajosaari, M., Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

4.7 WP7 Standard for decision making in crises (WP-leader: NTUA)

• A summary of progress towards objectives in WP7, Task 7.1:

WP7, coordinated by NTUA, was organized with the aim of testing the FLOODSTAND approaches in view of the mitigation of the casualty risk of passengers onboard ships associated with the ship flooding hazard; the testing was understood within laboratory environment. The two developed approaches of FLOODSTAND, to be tested, were those of the “FLOODSTAND for crisis management”, as elaborated in WP4-6, and the “FLOODSTAND for flooding control” approach, as elaborated in WP1-3.

The test conditions (benchmark scenarios for testing) were defined in task 7.1 for the ship in ‘operation’ (work of Task 7.2) and the ship in ‘design’ stage (work of Task 7.3). For the testing in the ‘operation’ mode (7.2), specific casualties and damage extents are considered, whereas differently in the ‘design’ mode some wider range of probable casualties was considered. The main challenges for the operational problem are the onboard detection of the damage case and subsequently the estimation of the ship’s survivability for the particular damage detected. The challenge for the design problem regards the assessment of the full, as much as possible, range of probable casualties throughout ship’s life. Operational problem may yield advice related to the evacuation of the damaged ships, whereas the design problem may drive decisions related to the watertight subdivision of the ships. The “FLOODSTAND for crisis management” was tested for both operational and design conditions (Tasks 7.2 and 7.3) according to the original work plan, whereas “FLOODSTAND for flooding control” was tested in operational only (Task 7.2) according to the modified work plan.

The “FLOODSTAND for crisis management” approach was tested by SSRC and BMT (Task 7.2), as implemented with the FLOODSTAND-ISTAND software, and was used to analyze two ships, one ROPAX (Estonia) and one cruise (Monarch), in real accident conditions. The conducted studies demonstrated that the results could be assumed as well correlated to the reported findings from the corresponding accident investigations; therefore they proved satisfactory for the developers (SSRC, BMT). However, due to the large uncertainty related to the detection of the damage extent, the onboard prediction remains accordingly of limited confidence. Furthermore, the studies put emphasis on the monitoring of the vulnerability of the ships due to the subdivision relaxations, which may result from the open watertight doors during ship operation. Thus, the associated risk might be well reduced before any flooding occurrence. This proactive function is considered of major importance particularly in view of the limited time for orderly abandonment, which is further confirmed in this project. The detailed work was reported with the deliverable D7.2a.

The “FLOODSTAND for flooding control” approach was tested by NAPA (Task 7.2), as implemented with the NAPA-Onboard software, and was used to analyze the flooding of two grounding casualties for one cruise ship, as they were defined in D7.1. The tests assumed some off-board setup (i.e. without estimations for the damage case/extent) for training purposes, and the collected results were to the satisfaction of the developers (NAPA). The method might be extended by exploiting additional information from water detection measurements, however it was not demonstrated. The consequences to the damage stability because of specific ship flooding could be computed with the tested tool, and awareness to the training crew could be provided. This was nicely demonstrated with the impact of watertight doors on the sinking of the damaged cruise vessel. The time performance of the flooding prediction tool needs still some improvement. The graphical user interface may improve functionality of the tool however contributes further to the computational requirements. The detailed work was reported with the deliverable D7.2b.

The "FLOODSTAND for crisis management" was also tested for ship design practice (Task 7.3). For this purpose the two passenger ships one RoPax (Estonia) and one cruise ship (concept design B, WP1) were tested by NTUA. Monte Carlo simulations were carried out to assess the probabilistic properties of the time to capsize, which is the fundamental variable of the approach, within a probabilistic design environment for collision side damages. The results enhanced evidences that that capsize events in collision damages systematically occur in short time (roughly 30 min) after the damage incident for both studied ships. This is quite short time to manage an orderly evacuation and abandonment of the ships, and particularly for the larger passenger ships. In this context, the applicability of the tested approach could not be concluded as the approach found to be insensitive in the range of the short times and for the generic probabilistic environment assumed. No remarkable impact of the alternative subdivision scenarios on the probabilistic properties the time to capsize could be detected. The detailed work was reported with the deliverable D7.3.

The three[6] technical reports D7.2a (by BMT), D7.2b (by NAPA) and D7.3 (by NTUA) were concluded within February 2012.

Significant results of this Work Package were:

- The onboard detection of the damage extent, which determines the ability to assess the ship's survivability, remains an open challenge for the onboard applications that deal with the survivability of the ship in flooding casualties.

- Additional evidences were generated indicating that the available time for orderly evacuation of both RoPax and cruise ships engaged in flooding incidents is much shorter than it is currently assumed. This may significantly affect the regulatory assumption for the safe evacuation of passenger ships.

Scientific publications (list):

- Spanos, D.A., Papanikolaou, A.D., On the Time Dependent Survivability of ROPAX Ships, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.
- Jalonen, R.P.S., Jasionowski, A., Ruponen, P., Mery, N., **Papanikolaou, A.**, Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.
- **Spanos, D., Papanikolaou, A.** (2011) On the time dependence of survivability of ROPAX ships, Journal of Marine Science and Technology, Vol. 17, pp. 40–46, DOI: 10.1007/s00773-011-0143-0
- Jalonen, R., Ruponen, P., Jasionowski, A., Maurier, P., Kajosaari, M., **Papanikolaou, A.** (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

[6] Note! Although formally treated as one deliverable, consisting of a cover document and two partial deliverables, D7.2a and D7.2b, the two latter documents are discussed here as two separate reports.

5. Conclusion

The progress of the work has been quite good and almost all of the objectives set to the first half and on the second half of the project were met. Project FLOODSTAND was established to derive most of the missing data for validation of time-domain numerical tools used in the assessment of ship survivability and to develop a standard for a comprehensive measure of damaged ship stability by concentrating on the risk of flooding. The results of the project obtained satisfied almost all of the identified objectives.

Nearly all of the scheduled RTD-deliverables could be produced in each Work Package and they could also be approved by the Steering Committee (SC) up to Mid-Term Meeting, i.e. during the first half of the project are listed as follows:

- WP1: 3 deliverables out of a total number of 3 deliverables (as planned)
- WP2: 11 deliverables out of a total number of 11 deliverables (as planned)
- WP3: 3 deliverables out of a total number of 3 deliverables (as planned)
- WP4: 5 deliverables out of a total number of 5 deliverables (as planned)
- WP5: 5 deliverables out of a total number of 5 deliverables (as planned)
- WP6: 2 deliverables out of a total number of 2 deliverables (as planned)
- WP7: 3 deliverables out of a total number of 3 deliverables (as planned[7])
- Total: 32 deliverables out of a total number of 32 deliverables (as planned)

The concept cruise ship designs in WP1were developed as planned, which gives good prospects for their further analysis during the second half of the project. In spite of the intentionally front heavy schedule of the experimental part of the work in WP2 and WP4, almost all of the scheduled tests could be made and reported during the first half of the project. The results from the model tests, and from the tests in real scale, as well as from the numerical analysis, and from all the other reported parts of the project, can be considered to be a good groundwork for further analysis and thus, a promising outcome of the project.

A standard for decision making in crises should be simple. In this respect the objective was met well. The proposed standard is simple. However, the other side of the coin should not be forgotten either. Unfortunately, a thoroughly made assessment of all the implications would require a multidisciplinary approach, possibly utilizing the methodology of Formal Safety Assessment, which was outside the scope of this Work Package and project.

The results of this project are published at the public website: http://floodstand.aalto.fi . Additionally, several journal articles and conference/workshop papers have been published, too, as well as documents for IMO's consideration (in SLF). All these results are part of and support pre-normative research towards guidelines, standards and regulations, and explanatory measures to assess their impact. The flooding calculations will be more reliable/easier for the ship designers to select novel design options. In this way the project helps the designers to better protect the vulnerable persons onboard. The improvement of the reliability of flooding simulations will increase the quality of onboard real time damage stability assessments and estimates of the safety onboard, which may be a very demanding task for any operator faced by the rare, but hazardous event of flooding.

[7] Note! Part of the work in WP3 was moved to WP7. This work, consisting solely of work efforts of NAPA, and its results are reported in partial deliverable D7.2b. Deliverable D7.2 is considered here to be one deliverable, as it officially should, composed of two partial deliverables D7.2a and D7.2b, and a cover document.

Ship designers, builders & ship owners, and the scientific community at large, on relevant workshops, journal and conference publications, as well as at scheduled presentations to the IMO, has formed the media of the results. The reception in all venues has proved to be encouraging.

FLOODSTAND will contribute in reducing the risk to human life, by ensuring that the level of safety of the transport system will respond to the increasing demand, featured by large passenger ships. Prospects for this development look encouraging, based on the results achieved during the final (second) 18-month period of the project.

6. References

RTD-deliverables of the project FLOODSTAND (218532) produced and approved include the following deliverables from Work Packages 1-7:

Del. no	Deliverable name	WP no.	Lead beneficiary	Nature
D1.1a	Concept Ship Design A	1	STX	R, P
D1.1b	Concept Ship Design B	1	MW	R, P
D1.2	Analysis and applicability of alternative design	1	STX	R
D2.1a	Description of the mockup and test procedures; List of structures to be tested	2	CTO	R, P
D2.1b	Experimental study on the critical pressure heads	2	CTO	R, P
D2.2.a	Numerical study on the critical pressure heads	2	MEC	R, P
D2.2.b	Guidelines and criteria on leakage occurrence modelling	2	STX	R
D2.3	Results of the experimental study on the pressure losses in openings	2	AALTO	R, P
D2.4.a	Results of the computational study on the pressure losses in openings	2	CNRS	R, P
D2.4.b	Results of the studies of pressure losses in air pipes and effects of ventilation	2	CTO, STX	R, P
D2.5a*	Draft report on flooding tests on detailed cabin arrangements	2	MARIN	R, P
D2.5b	Report on flooding tests on detailed cabin arrangements and on the effects of different scale	2	MARIN	R, P
D2.5.c*	Guidelines on modelling principles for cabin areas	2	MARIN	R, P
D2.6	Sensitivity analysis for the input data in flooding simulation. Criteria for floodwater flow modelling	2	AALTO	R
D3.1	Flood sensors data interpreter	3	NAPA	R
D3.2	Impact of ship dynamics	3	AALTO	R
D3.3	Design guidelines for disposition of flooding sensors	3	NAPA	R

D4.1 [8]	Report on physical model experiments with ship model	4	SSPA	R
D4.2	Report on validation and sensitivity testing of an analytical method for characterising ttc	4	SSRC	R, P
D4.3	Report on validation and sensitivity testing of a numerical method for characterising ttc	4	NTUA	R, P
D4.4	Report on validation and sensitivity testing of a hybrid method for characterising ttc	4	SSRC	R, P
D4.5	Report on the method for assigning of uncertainty bounds for methods for characterising of ttc	4	SSRC	R, P
D5.1	Report on the data collection on mustering/abandonment and rescue	5	BV	R
D5.2	Report on validation and sensitivity testing of methods for assessing effectiveness of mustering process	5	BMT	R, P
D5.3	Report on validation and sensitivity testing of methods for assessing effectiveness of abandonment process	5	BV	R, P
D5.4	Report on validation and sensitivity testing of methods for assessing effectiveness of rescue process	5	BV	R, P
D5.5	Report on the method for assigning of uncertainty bounds for methods for M-A-R assessment	5	SSRC	R, P
D6.1	Report on the details and the rationale of the loss function	6	SSRC	R, P
D6.2	Report on the details of the likelihood function	6	SSRC	R, P
D7.1	Report on the benchmark data on casualty mitigation	7	NTUA	R
D7.2 [8]	Report on the tests of the standard in a Functioning Crises Management System	7	BMT	R, P
D7.3	Report on the applicability of the standard for design practice	7	NTUA	R, P
	*Note! This is not a public report			

[8] Note! This deliverable includes a cover document and separate partial deliverables

Other scientific publications of the project:

Penttilä, P., Ruponen, P. (2010), Use of Level Sensors in Breach Estimation for a Damaged Ship. Proceedings of the 5th International Conference on Collision and Grounding of Ships ICCGS, June 14th - 16th 2010, Espoo, Finland, pp. 80-87.

Jalonen, R.P.S., Jasionowski, A., Ruponen, P., Mery, N., Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

Spanos, D.A., Papanikolaou, A.D., On the Time Dependent Survivability of ROPAX Ships, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

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Qi Chen, Jasionowski, A, "A New Methodology for Modelling Stochastically the Time to capsize", 4th International Maritime Conference on Design for Safety, October 18-20, 2010 in Trieste, ITALY.

Stening, M., Järvelä, J., Ruponen, P., Jalonen R., Determination of discharge coefficients for a cross-flooding duct, Ocean Engineering, Vol. 38 (2011), pp. 570–578.

Jasionowski, A., 2011. Decision Support for Ship Flooding Crisis Management", Ocean Engineering, Vol. 38 (2011), pp. 1568–1581..

Manderbacka, T.L., Matusiak, J.E., Ruponen, P.T. (2011) Ship Motions Caused by Time-Varying Extra Mass on Board. Proceedings of the 12th International Workshop on Ship Stability, Washington, D.C. USA - 12-15 June 2011, pp. 263-269.

Ruponen, P., Queutey, P., Kraskowski, M, Jalonen, R., Guilmineau, E. 2012a. On the calculation of cross-flooding time. Ocean Engineering Vol. 40 (2012), pp. 27-39.

Spanos, D., Papanikolaou, A. (2012) On the time dependence of survivability of ROPAX ships, Journal of Marine Science and Technology, Vol. 17, pp. 40–46.

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